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FOR

# CONFORMAL HEAT SINK


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# CONFORMAL HEAT SINK

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to cooling heat-generating electronic devices.

### Description of the Related Art

Many electronic devices and/or components generate heat during operation. Unless heat is removed to maintain a device within the appropriate operating temperature range, the speed, power, and useful lifespan of the device may be adversely affected. The problem of heat removal is often exacerbated when the device is mounted on a thermally non-conductive substrate, such as an epoxy-composite printed circuit board (PCB). In a typical electronic module, electronic devices are densely packed on a PCB resulting in a complicated surface topology of varying heights, shapes, and profiles.

Fig. 1 shows a three-dimensional perspective view of an electronic module **100** having attached three prior-art heat sinks **110a-c**. More specifically, module **100** includes a plurality of electronic devices, e.g., integrated circuits, mounted on a PCB **102**. Each heat sink **110** is attached to a corresponding group of devices, with all devices within the group preferably having similar shapes and dimensions. For example, heat sink **110a** is attached to a group having nine devices **104**, heat sink **110b** is attached to a group having nine devices **106**, and heat sink **110c** is attached to a group having six devices **108**. In addition, a heat sink similar to heat sink **110** may be attached to each individual heat-generating device, e.g., circuit **112**. Each heat sink **110** is fabricated of a material having good thermal conductivity, e.g., aluminum or copper, and has the shape of a plate with fins extending from one side of the plate to increase the effective surface area for heat dissipation. The opposite side of the plate is appropriately profiled to match the geometric shape of the group being cooled.

One problem with heat sinks similar to heat sink **110** is that it is tedious and expensive to design, fabricate, and install individual heat sinks for different individual heat-generating devices or groups of such devices, which are typically diverse in placement and shape.

## SUMMARY OF THE INVENTION

Problems in the prior art are addressed, in accordance with the principles of the present invention, by a conformal heat sink. In one embodiment, a heat sink of the invention includes a corrugated plate and a deformable membrane, attached to each other at the periphery to define an enclosed volume. The membrane has a metal foil layer, due to which it can be deformed to conform to a complicated surface geometry of the electronic module to be cooled. To mate the heat sink with

the module, air pressure is applied to the enclosed volume through a fitting to force the membrane into close contact with heat generating components of the module. When the air supply is disconnected, the membrane retains its shape due to the malleability of the foil layer. The enclosed volume is then filled with an appropriate heat-conducting fluid, which may optionally be circulated to facilitate heat removal from the module.

According to one embodiment, the present invention is a heat sink for cooling heat-generating electrical equipment having a surface profile, the heat sink comprising a plate and a deformable membrane attached to the plate to define an enclosed volume, wherein, when the heat sink is positioned in proximity to the equipment and a deformation force is applied to the membrane, the membrane conforms to the surface profile.

According to another embodiment, the present invention is a method of cooling heat-generating electrical equipment having a surface profile, the method comprising: (A) positioning a heat sink in proximity to the equipment, wherein the heat sink comprises a plate and a deformable membrane attached to the plate to define an enclosed volume; and (B) applying a deformation force to conform the membrane to the surface profile.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and benefits of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which:

Fig. 1 shows a three-dimensional perspective view of an electronic module having attached three prior-art heat sinks;

Figs. 2A-B show three-dimensional perspective and cross-sectional views, respectively, of a heat sink according to one embodiment of the present invention; and

Fig. 3 shows a cross-sectional view of an electronic module having attached the heat sink shown in Fig. 2 according to one embodiment of the present invention.

## DETAILED DESCRIPTION

Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments.

Figs. 2A-B show three-dimensional perspective and cross-sectional views, respectively, of a heat sink **210** according to one embodiment of the present invention. Heat sink **210** includes a top panel **212** and a deformable membrane **214**, both mounted on a support frame **216**. Panel **212** and

membrane **214** are attached to each other at the periphery to define an enclosed volume **220**. In a preferred implementation, volume **220** is an airtight volume accessible through a pair of fittings **222a-b**. Each fitting **222** is adapted to be connected to an external supply line, e.g., a compressed air line. When necessary, each fitting **222** may be plugged using an appropriate fitting cap.

Panel **212** has the shape of a corrugated plate to increase both the surface area of volume **220** and the effective external area of heat sink **210** for heat dissipation. In one implementation, membrane **214** has at least two layers, a metal foil layer and a thin dielectric layer (not shown). The foil layer provides malleability to membrane **214**, due to which it can be deformed into a desired shape and then retain that shape after the deformation force is removed. The dielectric layer is deposited onto the outer (i.e., corresponding to the exterior of heat sink **210**) surface of membrane **214** to provide electrical insulation, e.g., between the heat sink and any electronic devices it is in contact with. Conformational freedom of membrane **214** is enabled by the appropriate selection of membrane's size. More specifically, in a fully extended (unfolded) state, the area covered by membrane **214** exceeds by a selected amount (e.g., 30%) that of the planar cross-section of frame **216**. As will be further explained below, membrane material in excess of the planar cross-section area is used to conform the shape of heat sink **210** to a complicated surface geometry of the electronic module to be cooled.

Fig. 3 shows a cross-sectional view of an electronic module **300** having attached heat sink **210** (Fig. 2) according to one embodiment of the present invention. Module **300** is similar to module **100** (Fig. 1) and includes a plurality of irregularly shaped electronic devices **304-314** mounted on a PCB **302**. Heat sink **210** is mounted on PCB **302** using screws **316**, each attached between support frame **216** and the PCB. Using the pliability of membrane **214**, the membrane is molded to adapt to the shape of devices **304-314** and to provide good thermal contact between those devices and the membrane.

In one embodiment, the shape of heat sink **210** is conformed to that of module **300** as follows. First, empty heat sink **210** is mounted over the corresponding area of module **300** using screws **316**. Then, one of fittings **222a-b** is plugged and the other one is connected to a compressed air source. Air pressure is applied to volume **220** to push membrane **214** toward devices **304-314** and PCB **302**. The pressure value is selected such that membrane wraps over each device and is forced into the spaces between different devices thereby adapting to the shape of module **300**. When the air pressure is removed, membrane **214** retains its shape due to the malleability of its foil layer. A layer of thermally conducting grease may be placed between membrane **214** and devices **304-314** to further improve the thermal contact. Then, volume **220** is filled with an appropriate heat-conducting fluid, which facilitates heat flow from membrane **214** to panel **212**. In one embodiment,

the grease and/or fluid are selected from an assortment of thermally conductive gels commercially available from Gel Sciences, Inc., of Bedford, MA.

Optionally, the heat-conducting fluid may be circulated through heat sink **210** using an external circulation device (e.g., a pump) connected to fittings **222a-b** (Fig. 2). The circulation may be either continuous or intermittent. For example, intermittent circulation may be implemented as follows. Volume **220** is filled with a first portion of relatively cool fluid from an external reservoir. This portion is allowed to remain in heat sink **210**, e.g., until the fluid temperature rises, due to the heat generated in module **300**, to a certain selected value. Then, the first portion is pumped out of heat sink **210** and a next portion of relatively cool fluid is transferred into volume **220**.

In another embodiment, to conform the shape of heat sink **210** to that of module **300**, the heat sink is assembled *in situ* over the module, e.g., as follows. A sheet of membrane material is applied to module **300** to cover the selected area to be cooled. The sheet is then (i) creased to adapt to the shape of devices **304-314** and PCB **302** and (ii) cut around the periphery of the area to be cooled. Support frame **216** is then mounted on PCB **302** and the edge of the membrane is attached to the frame without disturbing the creased portion of the membrane covering devices **304-314**. Panel **212** is mounted onto frame **216** and the assembly is sealed around the periphery to form volume **220**. To obtain an airtight seal, frame **216** may incorporate suitable gaskets for the attachment of membrane **214** and panel **212**. Optionally, a glue or heat treatment may also be used to seal volume **220**. Since the shape of so assembled heat sink **210** is already adapted to the shape of module **300**, the step of applying air pressure, as described above, is no longer required.

In yet another embodiment, volume **220** of heat sink **210** is filled with a heat-conducting fluid prior to the heat sink attachment to module **300**. Preferably, the amount of fluid transferred into volume **220** is chosen such that the volume is in a floppy state, e.g., similar to that of a partially filled sandbag. Heat sink **210**, so filled, is then pressed against the surface of module **300** and secured thereon to produce the assembly shown in Fig. 3.

In various embodiments, heat sink **210** may be appropriately designed, for example, to have (i) relatively high turbulence of air and fluid flow around panel **212** for improved heat circulation and exchange, (ii) clips, springs, clamps, or other fasteners for ease of attachment to module **300** and/or (iii) a relatively large size to cover the entire PCB or circuit card. Due to the small thickness of membrane **214**, relatively expensive materials, e.g., gold, may be utilized in the membrane without prohibitively increasing the cost of the heat sink. Gases, liquids, gels, fine powders, or various mixtures thereof can be used to fill volume **220**. An active or passive heat-exchange device may be used, as known in the art, to cool the fluid circulated through volume **220**. More specifically, in an active heat-exchange device, a refrigerant or a thermo-electric cooler is brought into thermal contact with the circulating fluid. In a passive heat-exchange device, the fluid is cooled down via passive

dissipation of heat into the (cooler) environment. Advantageously, heat sinks of the invention are relatively easy to mate to different irregularly shaped heat-generating devices and/or modules.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications of the described embodiments, as well as other embodiments of the invention, which are apparent to persons skilled in the art to which the invention pertains are deemed to lie within the principle and scope of the invention as expressed in the following claims.

Although the steps in the following method claims, if any, are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those steps, those steps are not necessarily intended to be limited to being implemented in that particular sequence.